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81-10017

CR-143427

A PROGRESS REPORT TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

University Applications Program

Washington, D.C. 25046

(E81-10017) FOR MULTIDISCIPLINARY RESEARCH
ON THE APPLICATION OF REMOTE SENSING TO
WATER RESOURCES PROBLEMS Progress Report,
Aug. 1978 - Jul. 1979 (Wisconsin Univ.)
50 p HC A03/MF A01

N81-12494

Unclass

CSCI 08H 63/43 00017

For Multidisciplinary Research
on the Application of Remote Sensing
to Water Resources Problems

Research Funded Under Grant #NGL 50-002-127

August, 1978 - July, 1979

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Original photography may be purchased from
EROS Data Center

Sioux Falls, SD

57198

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I. INTRODUCTION

This progress report for NASA Grant NGL 50-002-127, Supplement No. 9 "Multidisciplinary Research on the Application of Remote Sensing to Water Resources Problems," at the University of Wisconsin-Madison is for the period from August 1, 1978 to July 31, 1979. The Director of the Environmental Monitoring and Data Acquisition Group (now the Environmental Remote Sensing Center), Professor Ralph W. Kiefer served as the Principal Investigator. The research was administered through the Institute for Environmental Studies.

Research on the application of remote sensing to problems of water resources was concentrated, beginning in 1976, on sediments and associated non-point-source pollutants in lakes. That work, except for one aspect, was concluded in this project year. Emphasis has shifted to further transfer of the technology of remote sensing to agencies which would use it, and to the refinement of equipment and programs for thermal scanning and the digital analysis of images. The use of technology developed on the NASA remote sensing project by associated research projects has continued this year to be an important contribution to many fields.

In the area of instruction, with the approval as an official graduate program at the University of Wisconsin-Madison, of the Master of Science and Doctor of Philosophy in Environmental Monitoring last year, many students are pursuing these programs. The development of these programs and their growth to this stature have been directly dependent on the stimulation provided by this research project.

As this project has completed its final year at full funding and enters the two years of reduced funding preparatory to its conclusion, efforts have been directed toward completing and documenting the development of techniques, assessing the future value of the techniques that have emerged, and preparing facilities and literature of value in the future application of this technology to new research problems.

THE STRUCTURE OF THIS REPORT

Section II. is the report of research projects funded wholly or in part by the NASA Grant.

Section III. contains the reports of associated projects: those projects that depend on techniques developed on the NASA remote sensing grant, or that have made contributions of techniques to this research project.

Section IV. has the institutional information about remote sensing research and instruction at the University of Wisconsin requested by the Technical Officer.

In Section V. publications emerging from the project, or closely related to it are listed.

The Appendix contains a paper that has depended upon basic techniques developed on the NASA remote sensing project.

II. PROGRESS ON FUNDED PROJECTS

Atmospheric Corrections

Professor Frank L. Scarpace
James Verdin, Research Assistant

A project involving the use of multi-band imagery to correct Landsat imagery for atmospheric effects has been proposed for a number of years. In May of this year (1979) photographic imagery was acquired over Green Bay Wisconsin coincident with a Landsat passover. The imagery was developed and found to be acceptable for the project. Since the Landsat imagery was not available from EROS until Fall of 1979, however, no analysis of the data was possible during 1978-79. The student involved in the research has developed a method of overlaying a digitized photograph with the Landsat, but is leaving the University in August of 1979. It is anticipated that another student will be involved in this project to complete the photographic/Landsat correlation during the 1980/81 academic year.

Sediment Plume Study

Professor Frank L. Scarpace
Linda Kalman, Research Assistant

The goal of this portion of the research was to determine how photographic imagery and, ultimately, satellite imagery are affected by various types and concentrations of sediment in lake water. The specific goals of this sub-project during the year were to (1) finish the film calibration procedures and (2) start to analyze mission imagery acquired the previous two summers. The first of these goals was accomplished and the second task was started.

Absolute calibration of film imagery was necessary to correct for atmospheric problems and to use the imagery for radiometric calibration of Landsat imagery. Previous work had allowed us to calibrate the lens for geometrical lens falloff.* We were next interested in determining the absolute relationship between the energy falling on the film and the relative exposure determined through normal sensitometric means. To this end, pictures of a calibrated lamp source were taken using several film and filter combinations.

After development and scanning with our Optronics P1700 scanning densitometer, average relative log exposure values were calculated for each image using existing computer programs. The average log exposures were calculated using training set programs which consisted of small subsets of pixels in the center of the lamp image. A calibration constant,

K, was calculated for each lamp image which is related to the relative exposure, E_{rel} , and energy spectrum of the lamp, $e(\lambda)$.

$$K = -\log E_{rel} + \log \left[\frac{\Omega \tau \Delta \lambda \int e(\lambda) \cdot F(\lambda) \cdot S(\lambda) \cdot d\lambda}{\int F(\lambda) \cdot S(\lambda) \cdot d\lambda} \right]$$

where Ω is the solid angle the lens subtends

τ is the exposure time

$F(\lambda)$ is the transmittance of the filter used

$S(\lambda)$ is the sensitivity of the film used

E_{rel} is the relative log exposure

$e(\lambda)$ is the energy spectrum of the calibration lamp

Ideally this K should be independent of all parameters and should only vary a small amount from lens-to-lens.

The experimental results seem to reflect this assumption with a determined K value for our system of

$$K = 1.51 + .03$$

There were a few data points as much as .1 larger or smaller than the above value.

To check on the accuracy of the calibration constants, the absolute log exposures were calculated for images of reflectance panels. The images were taken at the same time as incident flux radiometer measurements were made on the ground.

The imagery used for analysis was photographs of reflectance panels taken in September 1978 using narrow band filters. The imagery was acquired at a flying height of approximately 700 m AMT on a clear to light haze day. While the imagery was acquired, incident flux measurements were performed on the ground using the digital radiometer with the cosine detector. The reflectance of the panels placed on the ground was measured the next day with the digital radiometer. Three shades of panels were used; white, dark gray, and light gray. The imagery was scanned at 50 micrometers spot size. Training sets were established in the centers of the panel images and the program STATS was used to extract the average relative log exposure for the panel. The log exposures were corrected for lens falloff. The appropriate calibration factors found previously were applied to the corrected log exposures to yield absolute log exposures. The values were then converted to exposure, and divided by the product of $w \cdot t \cdot \Delta \lambda$ to yield the actual intensity (ergs/cm nm.sr.sec) incident on the lens surface.

$$E(\lambda) \text{ incident on filter} = 10^{\log(E_{\text{abs}})} * \left(\frac{1}{w * t * v_{\lambda}}\right) \text{ ergs/cm}^2 \text{ nm.sr.sec}$$

Assuming no atmospheric effects, and a Lambertian type panel reflectance, R, the light incident on the panel is

$$E(\lambda) \text{ inc. on panel} = E(\lambda) \text{ inc. on filter} * 1/R(\lambda) \text{ ergs/cm}^2 \text{ nm.sr.sec.}$$

At this point, an average value of E incident on the panel was calculated for each wavelength, by averaging the results from all panels. Relatively small variation in calculated exposures for a given wavelength from one panel to the next was found.

Since the panel was assumed to have a Lambertian surface, then the flux incident on the panel is merely $\pi * E(\lambda)$ incident on the panel. This value was computed for the three filters.

The flux incident on the detector radiometer (ergs/cm nm.sec.) was computed using the measured radiometer data and a calibration established earlier for the radiometer. The radiometer is equipped with a cosine detector (flat diffusing surface) for measuring incident flux from the hemisphere above the detector. The detector response was calibrated by placing the flat surface of the detector flush against the surface of the standard lamp face. The standard lamp has an intensity calibration (ergs/cm nm.sr.sec.). The relative exposures calculated in this fashion were in agreement with the measured fluxes by the radiometer within the expected accuracy of the film detector.

The general conclusion of this part of the study is that the absolute accuracy of an average of a number ($N > 3$) of relative exposure determinations from film imagery is about 10%. This is consistent with the log-detector character of the film.

*Kalman, L. and F.L. Scarpace, "Determination of Lens Falloff Through Digital Analysis of Photographic Imagery," submitted to Photogrammetric Engineering and Remote Sensing.

Soil Erosion Studies

Professor Ralph W. Kiefer
Donald R. Morris-Jones

Since the last progress report (which covered work completed up to about January of 1979), a number of tasks have been completed by Donald R. Morris-Jones, a doctoral candidate in Environmental Monitoring supported on this project through May of 1979. An abstract of the dissertation to be completed by Mr. Morris-Jones follows:

ABSTRACT

The Universal Soil Loss Equation (USLE) is a frequently used methodology for estimating soil erosion potential. A variety of types of geographic information (e.g. topographic slope, soil erodibility, land use, crop type and soil conservation practice) are needed in order to quantify soil loss with the USLE. Topographic maps, soil surveys, field surveys and interviews with farmers are the traditional sources of this information. In this study, methods for gathering the land use/land cover information required by the USLE were investigated with medium altitude, multi-date color and color infrared 70 mm positive transparencies and Landsat multispectral scanner data using human and computer-based interpretation techniques. In addition, the utility of computer geographic information systems for storing, displaying and quantifying USLE data was also considered. Successful results, which compare favorably with traditional field study methods, were obtained within the test site watershed with airphoto data sources and human airphoto interpretation techniques. Computer-based interpretation techniques, which were applied to digital airphoto and Landsat multispectral scanner data, were not capable of identifying soil conservation practices but were successful to varying degrees in gathering other types of desired land use/land cover information. For watershed and regional applications, computer geographic information systems provided a number of significant advantages (e.g. synoptic coverage, retention of spatial detail, capability of simulating land use changes and their effects, identification of areas with severe erosion problems, etc.) over traditional, tabular methods of data storage, display and manipulation.

The scope of the dissertation exceeds work completed under the NASA grant.

At present, Mr. Morris-Jones is in the final stages of completing multirate interpretations of airphotos in order to derive cropping management and support practice factor (i.e. C and P factors in the Universal Soil Loss Equation) values on a grid cell basis for the Pheasant Branch Watershed. These data will be stored in a detailed computer geographic

information system of the watershed which has been developed to permit quantification of USLE values on a grid cell basis.

Mr. Morris-Jones accepted a position as Research Engineer at the Environmental Research Institute of Michigan (ERIM) in the summer of 1979 and is working within the Earth Resources Data Center. Landsat data processing required for his dissertation will be conducted with ERIM facilities. Mr. Morris-Jones hopes to receive funding from contractors to develop and implement Landsat and other remote sensing based USLE information systems while at ERIM. Two proposals on this topic are presently under review.

Development of a Digital Image Processing Facility

Dr. Lawrence T. Fisher, Program Coordinator

In our report for the 1977-78 project year we described the proposed acquisition of a McIDAS (Man-Computer Interactive Data Access System) color terminal. It is expected that this terminal will allow us to use modern image-processing techniques which are now prohibitively expensive or slow.

The McIDAS terminal will operate from a Harris/6 computer that the Meteorology Department is securing. It is hoped that new interactions between information from meteorological satellites and that from Landsat will be developed as a fruitful area for research.

A second component of our image-processing facility, the control computer for the Optronics P-1700 Scanning Densitometer, is also being revised. The Space Science and Engineering Center (SSEC) is building an Intel microcomputer for control of the densitometer and tape drive to improve reliability and speed of the scanning process.

The technicians of SSEC are now constructing the densitometer controller and the McIDAS terminal, with delivery expected in September 1979. Shakedown and programming will commence in the fall, with full operation predicted by December 1979.

Conversion of programs for image analysis from the Univac 1110 format to that for the Harris/6 will be a formidable task, but completion of it should open many new areas of application of remote sensing for investigation.

Modifications to the Thermal Scanner

Dr. Lawrence T. Fisher

During this past year the data acquisition system for our TI RS-18A thermal scanner system has been changed from an analog recording system to an all digital recording system. The Sangamo Saber III tape recorder has been replaced by a micro-processor (Intel 80/10) and a Pertec 1600 BPI tape deck. The scanner video output is transformed into 12 bit digital values (in order to record the full dynamic range of the possible signal), then recorded in 4K byte records on the Pertec tape drive.

The modifications were field tested on Lake Superior in the summer of 1979. As far as could be determined, the system is working up to expectations. Future modification of the thermal scanner system will include a real-time video display of the imagery and the capability of some data analysis in the field.

III. ASSOCIATED PROJECTS

Demonstration Project to Evaluate the Opportunities for Operational Applications of Landsat Data in Wisconsin

Professor Frank L. Scarpace
Robert Yeadon, Research Assistant

The objective of this study, beginning in March 1979, was to demonstrate the use of Landsat data for the measurement of trophic status of inland lakes, in an operational setting in close cooperation with the user agency. The Wisconsin Department of Natural Resources, as part of its 208 Water Quality Program, must establish the trophic status of a large number of lakes. In this demonstration project, DNR scientists would operate the data extraction and analysis programs developed at the University of Wisconsin, in collaboration with University research scientists.

Original plans called for acquisition of Landsat computer-compatible tapes, extraction of data on the lakes in question, and analysis of the data--producing a list of lakes with trophic status indicated. Funds available for this demonstration, however, were adequate only for the acquisition of tapes and the commencement of data extraction. Analysis would have to wait on further funding becoming available.

Data have been extracted, and the project is ready for the next step as soon as funds become available.

Crop Yield Study

Professor Frank L. Scarpace
Thomas Mace, Research Assistant

The study of soybean crop yield using medium scale color and color infrared imagery to evaluate yield was completed. Methods were reported in our previous progress report (1977-78). Analysis was completed this year, and a final report prepared for Argonne Laboratory. A copy of the report is included as Appendix I to this report.

Computer-Aided Classification of Forest Cover Types

Thomas Mace, Research Assistant

The Department of Forestry of the University of Wisconsin, with the cooperation of the Environmental Remote Sensing Center, conducted this study to compare forest cover type classification by digital analysis of small-scale (1:120,000) aerial imagery to hand-drawn cover-type mapping from ground observation.

The study area was Bear Island, Wisconsin, in the Apostle Islands National Lakeshore. Ground data were gathered by stratified random sampling. Aerial image classification was done by converting a color infrared aerial photo with density wedge to digital form, and classifying types by computer programs based on maximum likelihood with threshold.

Results from the comparison of methods showed an average accuracy of 62% in the classification made by the computer-aided analysis of the small-scale aerial image. Greater accuracy could be expected if the original aerial data had been better adapted to this method. Imagery for optimum use of this method of classification should have the following characteristics:

Scale 1:50,000 to 1:100,000.

The density wedge should be attached to and processed with the film image.

Fall-off characteristics of the lens used for the original photo and filters used should be known in detail. No anti-vignetting filters should be used.

Images should be framed so that features to be classified are centered.

White reflectance panels should be included in the image when photographed.

If this method is used, and the suggested standards for imagery are met, greater accuracy can be expected, and maps of forest cover type can be made at substantially lower cost than by hand-drawing. This would greatly aid the National Park Service, which must map forest cover types over extensive areas in order to fulfill its goal of maintaining or reconstructing presettlement vegetation within National Parks and Monuments. The regular updating of these maps would also be accomplished more easily and at less cost.

Green Bay Project

Professor Frank L. Scarpace
Bruce Quirk, Research Assistant

This project involves development of techniques for mapping land cover from Landsat and digitized aerial photography for use in a hydrological runoff model. It is anticipated that the resultant data will be used by the Wisconsin Department of Natural Resources in their 208 Water Quality programs as well as by the United States Geological Survey for input to their streamflow-water quality models.

Thus far, Landsat and aerial imagery have been acquired for the test site. The aerial imagery has been converted to digital form and classification of test sub-watersheds has begun. The input of the land cover data to the sediment run-off models will be started during the next year.

This research is funded by the University of Wisconsin-Madison Sea Grant program.

Pheasant Branch Watershed Soil Study

Professor Ralph W. Kiefer
Akin Fapohunda, Graduate Student

The general perception in literature in a sense recognizes some limitations as to the degree of detail and accuracy that can be obtained using remote sensing. Thus it is agreed, for instance, that soil mapping at the association level can adequately be obtained even from spaceborne platform sensors such as Landsat. What is generally overlooked is that while this can be achieved in some places, it becomes increasingly difficult and perhaps impossible in others. For example, in terrains with relatively young geological and pedological age such as wetlands, the characteristics on which photographic processes are based are not fully expressed. Attempting the application of remote sensing in these areas is at best only possible with such a detailed level of field work to gather ground truth that whatever advantage results is eventually minimized.

The aim of this research is to demonstrate that the level of field work required for soil mapping using aerial photography varies spatially depending on terrain geology and complexity of soil association systems.

Three scenes, all in the Pheasant Branch Watershed in Dane County, Wisconsin, were selected for the purpose of this study. The interpretation to delineate recognizable soil bodies was done on the color additive viewer and zoom stereoscopes. Overlays of delineations obtained in the area covered by each photograph were prepared for field use.

Field work was carried out for four weeks during summer 1979. The results indicate significant variations in the amount of information contained in each photograph and consequently the amount of time required for field work to produce accurate soil classification using remote sensing techniques (in this case, color and color infra-red photography).

A detailed report of this work is being prepared for publication by May, 1980.

Mapping of Vegetation in the Sheboygan Marsh

Professor Ralph W. Kiefer
Professor Frank L. Scarpace
Bruce Quirk, Research Assistant

Since 1975 the remote sensing group has been studying methods for mapping vegetation in the Sheboygan Marsh, a wetland in central Wisconsin. Small-scale imagery (1:120,000) has been used to determine how useful it is for classification of vegetation in the wetland and how well the boundaries of the wetland can be delineated.

This study has been completed. A full report will be included in the next progress report.

Data Collection and Analysis Methods Used to Monitor Impacts Over Time in a Severely Disturbed Wetland

Professor Ralph W. Kiefer
Sarah L. Wynn, Research Assistant

The purpose of this study has been 1) to document wetland species and community change from 1975 to 1977 from the air and from the ground, and 2) to evaluate and compare the efficiency, sensitivity, and reliability of a variety of traditional and new data sampling and analysis techniques used to document this change. This study was part of a larger, ongoing Environmental Protection Agency study to monitor the impacts of the construction and operation of a coal-fired power plant located in a large wetland near Portage, Wisconsin.

The nine methods chosen for this study were evaluated on a basis of time, cost, sensitivity, and reliability and also on the bases of: whether they monitor vegetation change at a species or community level; whether they monitor community change in terms of change in area and/or location; and whether they provide information about community trends.

Four of the nine methods (diversity index, subjective classification, association analysis, and structure analysis) used ground sampling data. Two methods (airphoto monitoring and disturbance mapping) used airphoto data only, while airphoto grid analysis and airphoto interpreted vegetation mapping used airphoto and ground sampling data. The ninth method (computer-assisted mapping) used only airphoto data but relied heavily on the analyst's knowledge of the area.

A Ph.D thesis based on this work will be completed by December 1979.

COLUMBIA GENERATING STATION WETLANDS VEGETATION GROUP

Barbara Bedford

The Wetlands Plant Ecology Group of the Columbia Generating Station Impact Study has studied the effects of leakage from the station's cooling lake on wetland vegetation. The study included four phases: field inventory and classification of plant communities, vegetation monitoring, field and laboratory experiments to test hypotheses regarding the mechanisms controlling population changes, and assessment of field and theoretical approaches.

Results showed that changes in water levels and water temperatures caused by seepage from the cooling lake led to significant changes in wetland plant populations and communities within one year after the station began operation. In general, dominant perennial rhizomatous species of the genus Carex decreased in density and distribution, hydrophytic species such as Typha latifolia increased, and annual species such as Bidens cernua and Pilea pumila, which had been insignificant or absent before disturbance, increased markedly.

Results of community-level measures of wetland response to leakage from the cooling lake showed significant changes occurring in the structure of the plant communities. Major shifts in dominance and diversity patterns and a continuing trend of decreasing vegetative cover occurred. Open water and exposed mudflats replaced the previously closed and densely vegetated perennial plant communities over an increasing portion of the study area. Annuals colonized some of the habitat opened by the removal of perennial species, but large areas remained unvegetated. The plant commenced operation in 1975. By 1977, 19% of the quadrats sampled in the area of major impact had no rooted vegetation. Another 2% contained only annual vegetation.

This study indicated that prediction of the impact of such a disturbance on wetland vegetation will require a knowledge of the key characteristics of the life cycle of the plants involved.

Remote sensing of the wetland vegetation has been used by this group through analysis of medium-altitude aerial imagery acquired by the Environmental Remote Sensing Center using the airplane of the Wisconsin Department of Natural Resources. Analysis of photos has allowed the group to: 1) observe changes through time in spatial patterns of the vegetation, 2) map patterns of change in vegetation, 3) delineate the boundaries of areas of open water, 4) determine areas of high leakage from the cooling lake, 5) compare seasonal alterations in vegetation patterns caused by warm water leakage with control site seasonal variations, 6) locate areas of high temperature water during spring, fall, and winter.

Acquisition of data on the ground in this wetland is hazardous or impossible at certain times of the year due to the peculiar combination of water levels, floating mats of vegetation, and dense growth.

The study is funded by the U.S. Environmental Protection Agency.

IV. SUMMARY OF PROJECT ACTIVITIES

PROJECTS CONDUCTED WITH NASA FUNDS

<u>PROJECT</u>	<u>DATES</u>	<u>ACTION/DECISION</u>
<u>ATMOSPHERIC CORRECTIONS</u> Simultaneous low-altitude aerial photographs and landsat imagery have been acquired. Relations of these are analyzed to determine a means for correcting satellite	1976-79	Data acquired and preparations are being made for analysis
<u>SEDIMENT PLUME STUDY</u> Low and medium-altitude photographs of sediment plumes in an inland lake were acquired in two successive years during runoff events. Progress is being made in calibrating the images to determine if sediment concentrations can be measured by remote sensing of this kind.	1976-79	Film being calibrated. Sediment gradients are not readily measurable by this means.
<u>SOIL EROSION STUDIES</u> Medium altitude aerial photographs were analyzed to secure landcover for use with other factors in the Universal Soil Loss Equation to determine erosion due to runoff. Measurements by remote sensing are compared to those made by ground measurement.	1977-79	Remote sensing provides a practical means to determine some factors for the USLE.
<u>SCANNING DENSITOMETER CONTROLLER AND MCIDAS COLOR TERMINAL</u> A new computer and tape drive for use with the P-1700 Scanning Densitometer and a color McIDAS display and analysis terminal are being acquired to allow quicker and more precise image processing for both aerial photographs and Landsat images.	1978-79	Equipment is now being constructed
<u>MODIFICATIONS TO THE THERMAL SCANNER</u> The Texas Instruments RS-18A Thermal Scanner is being modified to record signals in digital rather than analog form.		Scanner is in operation. The reliability of operation seems much improved.

ASSOCIATED PROJECTS

These projects share technology with the NASA project, but are funded from other sources

<u>PROJECT</u>	<u>DATES</u>	<u>AGENCY FUNDING</u>	<u>ACTION/DECISION</u>
<u>GREEN BAY PROJECT</u> Development of techniques for mapping land cover from Landsat imagery and digitized aerial photographs for use in a hydrologic runoff model. Results may be used by the Wisconsin DNR in their 208 Water Quality Program, and by the USGS in streamflow-water quality models.	1978-81	Sea Grant	Data acquired analysis and model study under way.
<u>PHEASANT BRANCH WATERSHED SOIL STUDY</u> This study seeks to demonstrate that the level of field work required for soil mapping using aerial photographs varies spatially depending on terrain geology and complexity of soil association systems.	1978-79	Self-funded by student.	Significant variation found in the amount of information discernible from different photos and consequent differences in the field work required for accurate mapping.
<u>COMPUTER-AIDED CLASSIFICATION OF FOREST COVER TYPES FROM SMALL SCALE AERIAL PHOTOGRAPHY</u> High-altitude color infrared photographs of forests were analyzed to determine how accurately and at what costs forest cover types could be determined.	1978-79	University of Wisconsin Dept. of Forestry.	Accuracy of 62%, with many improvements suggested. Cost not calculated.
<u>DATA COLLECTION AND ANALYSIS METHODS USED TO MONITOR IMPACTS IN A WETLAND</u> Remote sensing by means of medium-altitude, color infrared aerial photographs is compared with ground surveys for monitoring changes to vegetation in a wetland.	1975-79	U.S. Environmental Protection Agency	Remote sensing is recommended as a tool for wetland monitoring

ASSOCIATED PROJECTS

These projects share technology with the NASA project, but are funded from other sources

<u>PROJECT</u>	<u>DATES</u>	<u>AGENCY FUNDING</u>	<u>ACTION/DECISION</u>
<u>COLUMBIA GENERATING STATION</u> <u>WETLANDS VEGETATION STUDY</u> Color infrared aerial photographs of a wetland adjacent to a power plant cooling lake were used to document vegetation community changes in the wetland.	1975-78	U.S. Environmental Protection Agency.	Remote sensing is a valuable technique providing a time-series record, and access to difficult areas for study.
<u>MAPPING OF VEGETATION TYPES IN SHEBOYGAN MARSH</u> From high altitude (1:120,000 scale) color infrared imagery, maps of the vegetation types in a wetland are being prepared and compared with field data.	1978-79	University of Wisconsin	Full report and correlations will be included in the 1979-80 progress report.
<u>DEMONSTRATION PROJECT TO EVALUATE THE OPPORTUNITIES FOR OPERATIONAL APPLICATIONS OF LANDSAT DATA IN WISCONSIN.</u> In cooperation with the Wisconsin Department of Natural Resources, this study seeks to classify lakes in Wisconsin by trophic status using Landsat. Classification is done by DNR personnel under supervision by University research personnel.	1979-80	NASA-ERRSAC	Funds for only a start in data extraction. Will seek more funds.

PROJECTS LISTED BY COOPERATING AGENCY

Federal

U. S. Geological Survey

SEDIMENT PLUME STUDY

U. S. Environmental Protection Agency

DATA COLLECTION AND ANALYSIS METHODS USED TO MONITOR IMPACTS IN A WETLAND
COLUMBIA GENERATING STATION WETLANDS VEGETATION STUDY

NASA - Eastern Regional Remote Sensing Applications Center

DEMONSTRATION PROJECT TO EVALUATE THE OPPORTUNITIES FOR OPERATIONAL
APPLICATIONS OF LANDSAT DATA IN WISCONSIN

State

Wisconsin Department of Natural Resources (DNR)

SEDIMENT PLUME STUDY
ATMOSPHERIC CORRECTIONS
SOIL EROSION STUDIES
MODIFICATIONS TO THE THERMAL SCANNER
MAPPING OF VEGETATION TYPES IN THE SHEBOYGAN MARSH
DEMONSTRATION PROJECT TO EVALUATE THE OPPORTUNITIES FOR OPERATIONAL APPLICATIONS
OF LANDSAT DATA IN WISCONSIN

Wisconsin Geological Survey

SEDIMENT PLUME STUDY
SOIL EROSION STUDIES
GREEN BAY PROJECT
PHEASANT BRANCH WATERSHED SOIL STUDY

Regional

Wisconsin Power and Light Company

DATA COLLECTION AND ANALYSIS METHODS USED TO MONITOR IMPACTS IN A WETLAND
COLUMBIA GENERATING STATION WETLANDS VEGETATION STUDY

Local

City of Middleton

SEDIMENT PLUME STUDY

PROJECTS LISTED BY SOURCE OF IMAGERY

Landsat Imagery

ATMOSPHERIC CORRECTIONS
SCANNING DENSITOMETER AND McIDAS COLOR TERMINAL
GREEN BAY PROJECT
DEMONSTRATION PROJECT TO EVALUATE THE OPPORTUNITIES FOR OPERATIONAL APPLICATIONS
OF LANDSAT DATA IN WISCONSIN

High Altitude Imagery

GREEN BAY PROJECT
COMPUTER-AIDED CLASSIFICATION OF FOREST COVER TYPES FROM SMALL-SCALE
AERIAL PHOTOGRAPHY
MAPPING VEGETATION TYPES IN SHEBOYGAN MARSH

Medium Altitude Imagery

SEDIMENT PLUME STUDY
SOIL EROSION STUDIES
PHEASANT BRANCH WATERSHED SOIL STUDY
DATA COLLECTION AND ANALYSIS METHODS USED TO MONITOR IMPACTS IN A WETLAND
COLUMBIA GENERATING STATION WETLANDS VEGETATION STUDY

Low Altitude Imagery

SEDIMENT PLUME STUDY
ATMOSPHERIC CORRECTIONS

OTHER FUNDING RECEIVED

These amounts, related to the capabilities generated by this grant, are not auditable, since they represent portions of larger grants based on our estimate of the cost of that part related to remote sensing.

Federal Agencies

U. S. Environmental Protection Agency	\$35,000
NASA - Eastern Regional Remote Sensing Applications Center	\$9,860

State Agencies

University of Wisconsin-Madison	\$58,000
Wisconsin Department of Natural Resources	\$2,000
Sea Grant Program	\$39,000

EDUCATIONAL ACTIVITIES

Professor Scarpace participated in a series of discussions with the Wisconsin Department of Natural Resources on plans for a program of classification of Wisconsin lakes using Landsat, under funding from NASA, ERRSAC.

Professor Kiefer continued his work as a member of the State of Wisconsin Interagency Wetlands Mapping Advisory Committee. Plans for remote sensing activities for all State agencies concerned with wetlands mapping are coordinated by this committee.

The following courses in Remote Sensing were offered on campus, with enrollments as shown:

<u>Course Number</u>	<u>Credits</u>	<u>Course Name</u>	<u>Enrollment</u>
CEE/IES-552	3	Remote Sensing of the Environment	42
CEE 554	3	Fundamentals of Remote Sensing	14
CEE 555	3	Airphoto Interpretation	46
IES/CEE/LA-556	3	Remote Sensing Image Interpretation	12
CEE 351	3	Photogrammetry for Non-Engineers	14
CEE 356	3	Photogrammetry	39
IES/CEE 920	3	Environmental Monitoring Seminar	15

Numerous courses dealing with advanced photogrammetry, surveying, and cartography are also offered. Master of Science and Doctor of Philosophy degrees with an emphasis on Remote Sensing can be earned in either the Department of Civil and Environmental Engineering or in the interdisciplinary Environmental Monitoring Program.

AGENCY CONTACTS

Federal

Environmental Protection Agency: Dr. Gary Glass, Research Chemist,
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Tennessee Valley Authority: Allan Voss, Remote Sensing and Photogrammetry
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State

Wisconsin Department of Natural Resources: GEF 2
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John M. Cain, Chief, Water Quality Planning Section,
John G. Konrad, Chief, Special Studies Section,
Jerome R. McKersie, Chief, Water Quality Evaluation Section
Francis Schraufnagel, Chief, Water Quality Section.

Wisconsin Geological Survey: 1815 University Ave. Madison, WI 53706
Arthur Ziegler, State Cartographer

TRAFFIC TO THE ENVIRONMENTAL REMOTE SENSING CENTER

Requests for Landsat Imagery	35
Requests for aerial photographic imagery	45
Contacts by citizens seeking information on remote sensing	5
Inquiries from State and local agencies	15
Consultations with other research or instructional staff for consideration of applications of remote sensing	25

GRADUATES OF THIS PROGRAM

Steve Fraton, Natural Resource Data Management Study,
New England Water Basin Commission,
Boston, Mass.

James Verdin, Water Resources Program
Colorado State University
Fort Collins, Colo.

Donna Stetz, EROS Data Center
Applied Science Division
Sioux Falls, S.D.

V. PUBLICATIONS

Members of the research team wrote or contributed to the following publications during this project year. Some of these were listed in the previous progress report, but are included here because they came out during the period covered by this report.

Allord, G., and F. L. Scarpace, "Improving Stream Flow Estimates Thru the Use of Landsat," Proceedings, AWRA Satellite Hydrology, June 1979.

Eahart, J., E. Joeres, and J. Hoopes, "Optimization of Waste Removal for Wide, Shallow Rivers," Journal of the Environmental Engineering Division, American Society of Civil Engineers, 1978.

Fisher, L. T., F. L. Scarpace, and R. Thompson, "Multidate Extraction Procedures for Landsat Lake Quality Monitoring," Photogrammetric Engineering and Remote Sensing, Vol. 45, No. 5, May 1979.

Green, T., J. Hoopes, F. Scarpace, J. Villemonte, and R. Madding, "Measuring Effluent Plumes," Proceedings of the ASCE Conference on Hydraulic Research, August 1978.

Green, T., and R. Terrell, "Airborne Radiometer Measurements of the Keweenaw Current," Journal of Geophysical Research, 83, pp. 419-426, 1978.

Kalman, L., and F. L. Scarpace, "Determining Lens Fall-off Through Digital Analysis of Photographic Imagery," Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry, March 1979.

Lillesand, Thomas M., and Ralph W. Kiefer, "Remote Sensing and Image Interpretation", 1979, John Wiley and Sons, Inc., New York, N.Y., 612 pages.

Meinert, D., D. Malone, A. Voss, and F. L. Scarpace, "Trophic Classification of Tennessee Valley Area Reservoirs Derived From Landsat Multispectral Scanner Data," Tennessee Valley Authority Technical Report, November 1978.

Morgan, Ken M., Gerhard B. Lee, Ralph W. Kiefer, T. C. Daniel, Gary Bubenzer, and John T. Murdock, "Prediction of soil loss on cropland with remote sensing," Journal of Soil and Water Conservation, Nov.-Dec. 1978, Vol.33, Number 6, pp.291-293.

Morgan, Ken M., Donald R. Morris-Jones, Gerhard B. Lee, and Ralph W. Kiefer, "Cropping Management Using Color and Color Infrared Aerial Photographs," Photogrammetric Engineering and Remote Sensing, Vol. 45, No.6, June 1979, pp.769-774.

Morris-Jones, D. R., Ken M. Morgan, R. W. Kiefer, and F. L. Scarpace, "Remote Sensing as a Source of Land Cover Information Utilized in the Universal Soil Loss Equation," Thirteenth International Symposium on Remote Sensing of Environment, April 1979.

Scarpace, F. L., T. Green, and R. Madding, "A Thermal Scanning Study of Coastal Upwelling in Lake Superior," Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry, March 1979.

Scarpace, F. L., K. Holmquist, and A. Voss, "An Investigation of Atmospheric Corrections to Landsat Data," Proceedings of the AWRA Satellite Hydrology Conference, June 1979.

Scarpace, F., "Densitometry on Multi-emulsion Imagery," Photogrammetric Engineering and Remote Sensing, Vol.44, No.10, October 1978.

Scarpace, F. L., and G. A. Friedrichs, "A Method of Determining Spectral Analytical Dye Densities," Photogrammetric Engineering and Remote Sensing, Vol.44, No. 10, October 1978, pp.1293-1301.

Scarpace, F. L., D. Meinert, D. Malone, and A. Voss, "Trophic Classification of Tennessee Valley Area Reservoirs," Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry, March 1979.

Scarpace, F. L., T. Green, and R. Madding, "A Thermal Scanning Study of Coastal Upwelling in Lake Superior," Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry, March 1979.

Scarpace, F. L., and T. Green, "The Spatial Variability of Coastal Surface Water Temperature During Upwelling," Journal of Physical Oceanography, Vol.9, No.3, May 1979.

Scarpace, F. L., K. Holmquist,, and L. T. Fisher, "Landsat Analysis of Lake Quality," Photogrammetric Engineering and Remote Sensing, Vol.45, No.5, May 1979.

APPENDIX

UNIVERSITY OF WISCONSIN-MADISON
Institute for Environmental Studies
FINAL REPORT - Purchase Order No. 955213

REPORT TO ARGONNE NATIONAL LABORATORY:

Microdensitometric Analysis of Aerial Photographic Imagery
for Yield Prediction in SO₂ and Acid Rain-Damaged Soybeans

by

Thomas H. Mace
Frank L. Scarpace

February 20, 1980

IMAGERY ACQUISITION

Aerial Photography

Aerial photography was taken over the study area on 22 August, 29 August, and 6 September 1978. Three 70 mm Hasselblad cameras were vertically mounted in a Cessna 180 aircraft. All cameras were equipped with 80 mm focal length lenses, and each mission consisted of passes at 610, 1220, and 1830 meters above ground level. Camera 1 was loaded with Kodak 2448 (color reversal) film and equipped with a haze filter; camera 2 was loaded with Kodak 2443 (color infrared reversal) film and equipped with a yellow (#12) filter; and camera 3 was loaded with Kodak 2403 (tri-x, panchromatic negative) film and no filter. All film had been stored frozen and was shipped to Precision Photo Lab Inc., Dayton, Ohio (via air courier) for sensitometry and processing.

Upon receipt of the processed film, we discovered that the film from the 22 August mission had been improperly exposed and was of marginal value. Apparently, the magazines holding the color and color infrared film had been switched, resulting in the color film being exposed through a yellow filter, and the color infrared film having been exposed through a haze filter. Similarly, processed tri-x was substituted for unexposed tri-x, making the imagery from camera 3 unusable as well. All other imagery appeared to be exposed properly and to be processed correctly.

Scanning

Table 1 lists the imagery scanned by: frame number, date of photography, film type, and nominal scale. All images were scanned on an Optronics P1700 rotating-drum-type scanning microdensitometer at an aperture/raster setting of 50 μ m. The data for each image, and its corresponding film wedge, were written on magnetic tape.

TABLE 1. IMAGERY SCANNED - ALL SCANNED AT 50 μ SPOT SIZE

FRAME NUMBER	DATE	FILM	NOMINAL SCALE
62-457-25	29 Aug 78	Color	1:7620
62-457-3	29 Aug 78	Color	1:30480
62-458-20	6 Sep 78	Color	1:7620
62-458-4	6 Sep 78	Color	1:30480
62-456-25	29 Aug 78	CIR	1:7620
62-456-3	29 Aug 78	CIR	1:30480
62-455-21	6 Sep 78	CIR	1:7620
62-455-4	6 Sep 78	CIR	1:30480
62-459-3	29 Aug 78	TRI-X	1:30480
62-459-25	29 Aug 78	TRI-X	1:7620
62-460-3	6 Aug 78	TRI-X	1:30480
62-460-9	6 Aug 78	TRI-X	1:7620
*60-782-2	22 Aug 78	CIR	1:30480
*60-782-22	22 Aug 78	CIR	1:7620
*60-783-4	22 Aug 78	Color	1:30480
*60-783-24	22 Aug 78	Color	1:7620

The multi-emulsion films (color and color infrared) were scanned three times over the same area. One of three narrow band (10 nm bandwidth) filters was placed in the optical path, such that the three scans recorded data in the blue (.45 μ m), green (.55 μ m), and red (.65 μ m) regions of the spectrum. These data are proportional to the integral dye densities of the three film layers (at the three measurement wavelengths) and are related to exposures from the field by the sensitometric film wedge and the characteristics of the film dyes (Scarpace, 1978.).

The single-emulsion images (tri-x), and their corresponding film wedges, were scanned once (through the 550 nm filter). The density/exposure relationship, in this case, is expressed by the film wedge alone, as no dye interactions are present.

Thus, the result of scanning was that the images were transformed into digital arrays (1200 x 1200 x 3 for color and color infrared, and 1200 x 1200 x 1 for tri-x) of density measurements every 50 μ m spatial location on the film. These 50 μ m measurements are commonly called "picture elements" (or "pixels") and consist of integers from 0 to 255 corresponding to densities from 3D to 0D, respectively.

IMAGERY ANALYSIS

Imagery Selection and Correction

The images from the 29 August mission were selected for intensive analysis. The multirate aspect of the study was abandoned due to the poor condition of the 22 August imagery and the lack of adequate reference points in the 6 September imagery.¹ It was decided, therefore, to analyze the data with respect to sensor (film type) and scale.

Correction of the data sets for dye interactions and lens falloff were performed according to the procedures outlined in Scarpace (1978) and Kalman and Scarpace (1979). The values stored for each pixel were, therefore, relative log exposures which had been scaled from 0 to 255.

Data Extraction

Line printer character maps of the corrected data arrays were made, and the locations of the field plots were outlined. The data points within the outlines were extracted and a mean vector for each plot was calculated.

¹The dispersal pipes were used for photogrammetric control and in locating the plots. These pipes had been removed by 6 September, and it was felt that we could not locate the plots as accurately on that date. Thus, a multirate evaluation might not be strictly valid.

These means were passed to another program which transformed the scaled mean relative log exposures to relative exposures (unscaled, real numbers). These mean exposures were subsequently used for statistical analysis.

Additionally, two methods were used to achieve lumped means as well as individual plot means for each treatment. The first method was to simply calculate means by plot (ie. 1LC-1, 1LC-2, 1LC-3, etc.) The second method involved merging the data from the four common treatment types and then calculating the means. Further, inspection of the large scale imagery (1:7620) revealed that every other data row corresponded to a plant row. Therefore, pixels whose values indicated they were non-plant pixels (ie. shadow and soil) were removed from the merged plots before calculating the means. It should be noted, however, this could only be done for the 1:7620 scale imagery.

Regression Analysis

Tables 2 and 3 summarize the results of the regressions performed using the MINITAB program package on the University of Wisconsin Univac 1110 computer. The terms "ALL," "SO₂," and "A.R. & SO₂" refer to the two separate experiments taken together, then individually. In each case, corresponding control plots were included. The expressions in parentheses indicate which spectral bands were used as predictors for yield. The term "(4,5,6)" was used when the three predictors were: 1) blue, green, and red bands for color film, 2) green, red, and infrared bands for color infrared film, or 3) a single broad band over blue, green, and red for the black and white panchromatic film. Method A refers to no merging or masking of plots, and method B refers to plots which had been merged and masked (1:7620 only). The values of R² ranged from 3.1% to 91.6%, and the values of S ranged from 88.8 kg/ha to 247.0 kg/ha.

The results were sometimes conflicting, but, generally, in accordance

with what one would expect. Method B was usually an improvement over method A. This may be partially the result of more points being used for each mean calculation and partially the result of fewer points being used for the linear regression. Except for large scale acid rain experiment plots, 3 predictors were better than 2, and the individual band predictors followed in the order: red, green, infrared, and blue.

Some interesting differences occur when one compares the regressions from the SO_2 plots to the regressions from the acid rain plots. There was a sharp increase in the usefulness of the infrared data when the acid rain plots were analyzed. This was particularly true for the low altitude (large scale) data. This would indicate that acid rain changes the infrared reflectance of the leaves in a way which is more related to yield than does SO_2 .

However, one must consider this phenomenon more an observation than a conclusion. We suspect that there may be interactions occurring between the variables which are not completely represented by our data. For example, the general improvement (in all but the infrared regressions) in R^2 for the acid rain plots with an increase in flight altitude is perplexing.

R²%

Film Type	COLOR		COLOR IR		TRI-X		COLOR		COLOR IR		TRI-X	
Frame:	457-25		456-25		459-25		457-3		456-3		459-3	
Plots (Bands)												
ALL(4,5,6)	68.9	81.0	54.8	65.0	66.1	59.3	58.9	73.7	69.2	80.4	22.4	45.0
(G,R)	53.4	63.1	52.9	62.4	-	-	58.8	73.2	62.6	74.8	-	-
(B)	19.3	8.1	-	-	-	-	36.9	38.2	-	-	-	-
(G)	43.5	57.0	48.9	47.2	-	-	53.1	62.1	56.5	71.0	-	-
(R)	-	-	52.9	62.2	-	-	53.9	70.7	60.4	71.3	-	-
(IR)	-	-	14.5	48.0	-	-	-	-	55.8	68.7	-	-
SO ₂ (4,5,6)	70.5	91.6	53.3	81.3	71.4	86.8	54.3	72.1	67.5	91.6	11.6	31.3
(G,R)	53.7	64.7	52.7	74.3	-	-	54.3	72.1	59.4	73.6	-	-
(B)	19.2	3.1	-	-	-	-	37.4	52.6	-	-	-	-
(G)	44.6	61.1	48.8	71.4	-	-	49.4	65.2	53.1	73.0	-	-
(R)	53.5	64.4	52.6	69.3	-	-	49.6	68.1	57.9	68.4	-	-
(IR)	-	-	11.5	38.5	-	-	-	-	54.2	63.5	-	-
A.R.(4,5,6)	74.2	78.8	77.4	89.3	50.5	32.5	75.5	75.2	80.6	80.4	67.5	69.4
& (G,R)	59.3	60.3	60.8	56.2	-	-	74.8	74.4	80.5	80.2	-	-
SO ₂ (B)	12.5	16.5	-	-	-	-	33.0	32.4	-	-	-	-
(G)	28.6	48.5	47.4	14.9	-	-	58.0	54.3	64.0	65.7	-	-
(R)	48.7	60.0	59.2	53.6	-	-	74.2	74.4	79.7	79.3	-	-
(IR)	-	-	76.7	78.5	-	-	-	-	62.8	74.3	-	-

Method: A B A B A B A B A B A B

1:7620

1:30400

TABLE 2. LINEAR REGRESSION ANALYSIS SUMMARY

S kg/ha

Film Type: Frame:	COLOR 457-25		COLOR IR 456-25		TRI-X 459-25		COLOR 457-3		COLOR IR 456-3		TRI-X 459-3	
Plots (Bands)												
ALL(4,5,6)	133.0	110.0	168.0	149.0	138.0	149.0	155.0	130.0	134.0	112.0	208.0	172.0
(G,R)	163.0	147.0	164.0	149.0	-	-	158.0	126.0	146.0	122.0	-	-
(B)	212.0	224.0	-	-	-	-	128.0	124.0	-	-	-	-
(G)	177.0	153.0	169.0	170.0	-	-	162.0	144.0	156.0	126.0	-	-
(R)	166.0	143.0	162.0	144.0	-	-	160.0	126.0	149.0	125.0	-	-
(IR)	-	-	218.0	168.0	-	-	-	-	157.0	131.0	-	-
SO ₂ (4,5,6)	133.0	88.9	168.0	133.0	127.0	91.1	166.0	162.0	140.0	83.0	233.0	203.0
(G,R)	164.0	163.0	166.0	139.0	-	-	163.0	145.0	154.0	141.0	-	-
(B)	214.0	247.0	-	-	-	-	188.0	173.0	-	-	-	-
(G)	177.0	156.0	170.0	128.0	-	-	169.0	143.0	163.0	130.0	-	-
(R)	162.0	149.0	163.0	139.0	-	-	169.0	142.0	154.0	141.0	-	-
(IR)	-	-	223.0	197.0	-	-	-	-	161.0	151.0	-	-
SO ₂ (4,5,6)	139.0	134.0	130.0	95.4	163.0	196.0	135.0	145.0	121.0	129.0	132.0	132.0
& (G,R)	159.0	164.0	156.0	173.0	-	-	125.0	132.0	110.0	116.0	-	-
A.R.(B)	216.0	218.0	-	-	-	-	189.0	196.0	-	-	-	-
(G)	195.0	171.0	168.0	220.0	-	-	159.0	161.0	139.0	140.0	-	-
(R)	166.0	151.0	148.0	162.0	-	-	117.0	121.0	104.0	109.0	-	-
(IR)	-	-	112.0	111.0	-	-	-	-	141.0	121.0	-	-

Method:	A	B	A	B	A	B	A	B	A	B
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1:7620

1:30400

TABLE 3. STANDARD DEVIATION SUMMARY

Yield Classification

A parallelepiped classification algorithm was written which, for each pixel, first calculated yield from a specified regression equation and then placed that pixel in a yield class based on selected ranges. Pixels whose calculated yield did not fall in any of the specified ranges were designated unclassified.

A subset of image 62-456-3 was classified using this method. The regression equation of:

$$Y = 1059. - 715000X_1 + 629000X_2 - 78347X_3$$

where:

Y = predicted yield (kg/ha)

X_1 = relative exposure of the green-sensitive layer

X_2 = relative exposure of the red-sensitive layer

X_3 = relative exposure of the infrared-sensitive layer

was used to calculate predicted yield for each pixel. This image and regression equation combination was chosen to maximize R^2 and minimize scale. The regression was derived from SO_2 plots only (1LC, 1L, 2LC, 2L, MC, M, HC, and H) and utilized 3 predictors (band 4, band 5, and band 6). Additionally, plots for a particular treatment were merged prior to the regression (method B). The sensor used was color infrared film at a scale of 1:30,675. R^2 and S may be found by reference to table 2 and table 3.

Figure 1 graphically depicts the way in which the class intervals were chosen. The ranges in measured yields were plotted for each treatment type, and then, the ranges for the class intervals were selected to correspond to the differences between the measured yields.

Figures 2, 3, 4, 5, and 6 are colored CRT displays of the classification and successive generalization routines. Figure 2 serves to illustrate the

graphics overlay procedure and the location of the plots in the classified scene. Corresponding line printer maps may be found in the appendix. The classified area represents a scene 141 rows by 116 columns or 216 M in the N-S direction by 178 M in the E-W direction (each pixel is approximately 1.53 M on a side.) For orientation purposes, the dirt road east of the plots is depicted on the extreme right of the figures by a series of unclassified pixels in a vertical string. The class intervals and their associated colors appear in the legend boxes at the extreme right. Again, the yield ranges correspond to those delineated in figure 1.

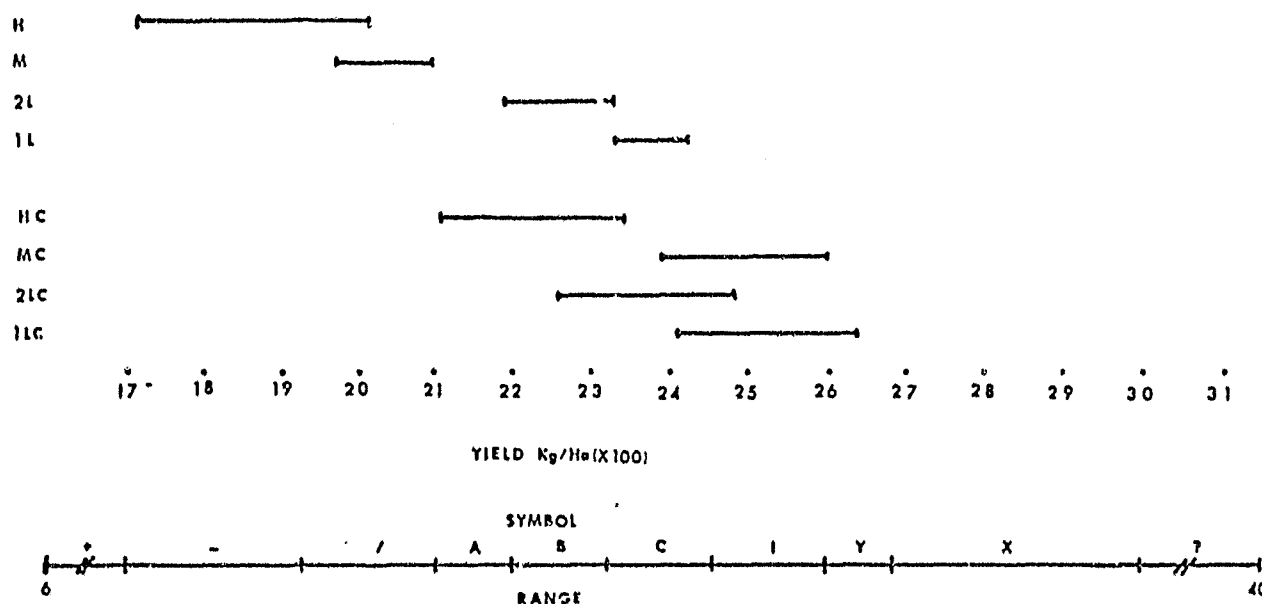


Figure 1. Measured Yield and Class Interval Ranges.

Analysis of figure 3 indicates that, on a per pixel basis, there is considerable variation in yield even within a plot. Generally, higher yields are associated with the controls, and lower yields are associated with the SO_2 damaged plots. However, more pixels were assigned to the ranges 600-1700 and 3000-4000 kg/ha than any other classes. These ranges seem to be probably outside the expected yields. Therefore, one must conclude that the relationship between yield and exposure is valid for a relatively narrow range. Perhaps a better equation could be found if a greater range of control plots could be found.

Figures 3, 4, and 5 are the result of generalization routines. Pixels were reassigned to classes depending on the classes of their nearest neighbors. Figure 4 seems to be the best compromise between interpretability and accuracy. However, this is a qualitative judgement as no other plots were available for an independent measure of accuracy.

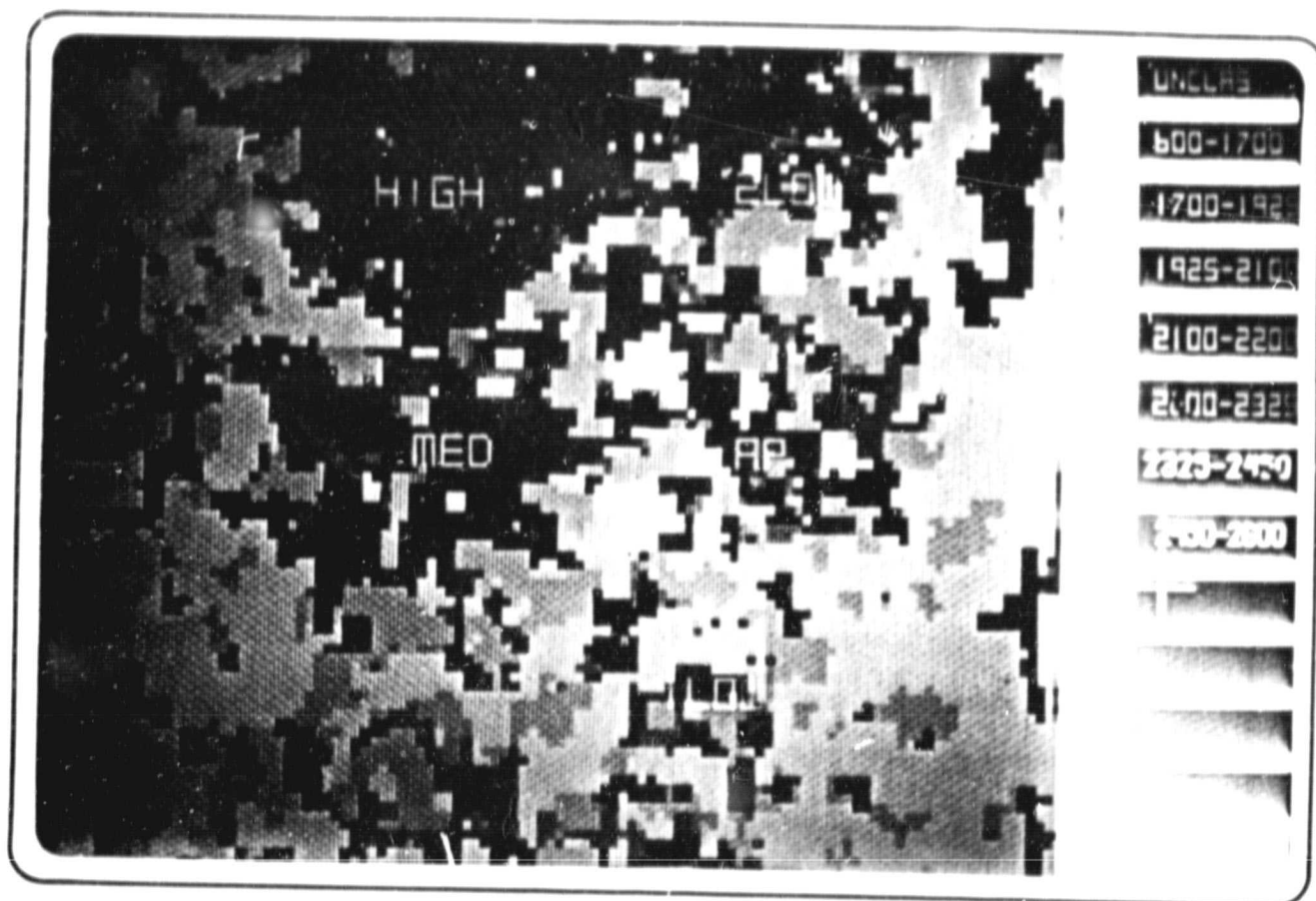


Figure 2. Graphics Overlay.

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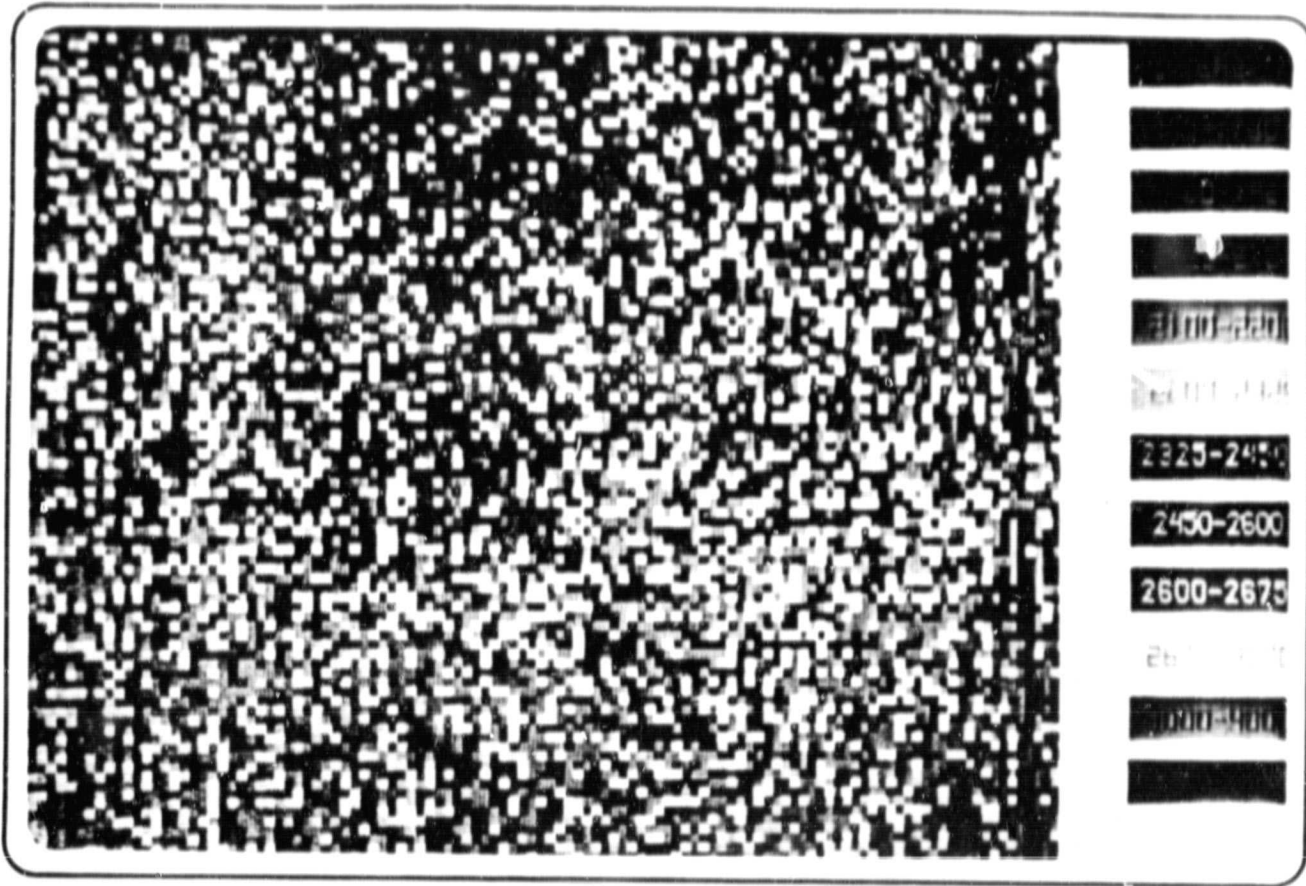


Figure 3. Yield Classification.

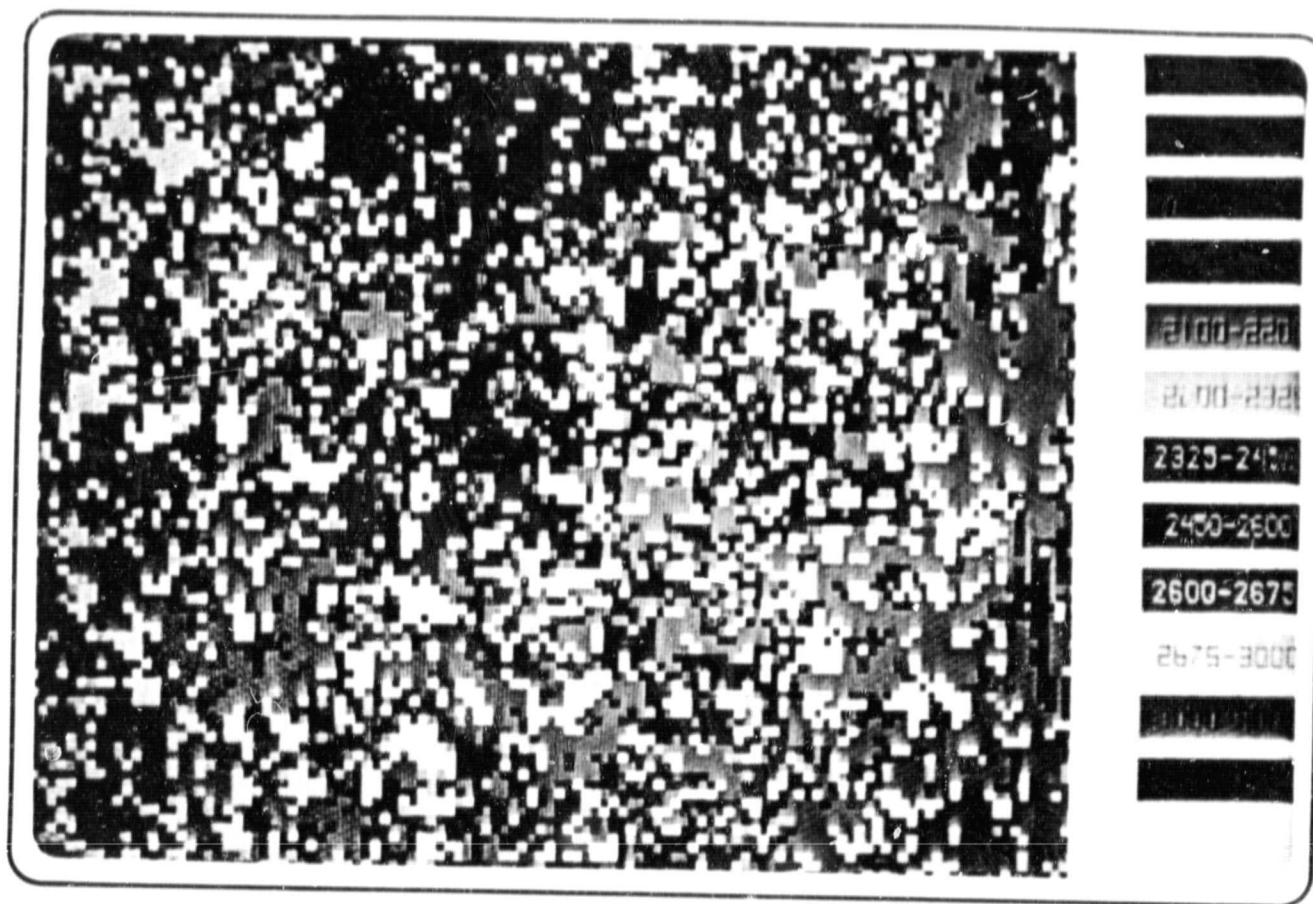


Figure 4. Smoothed Classification Preserving Linear Features.

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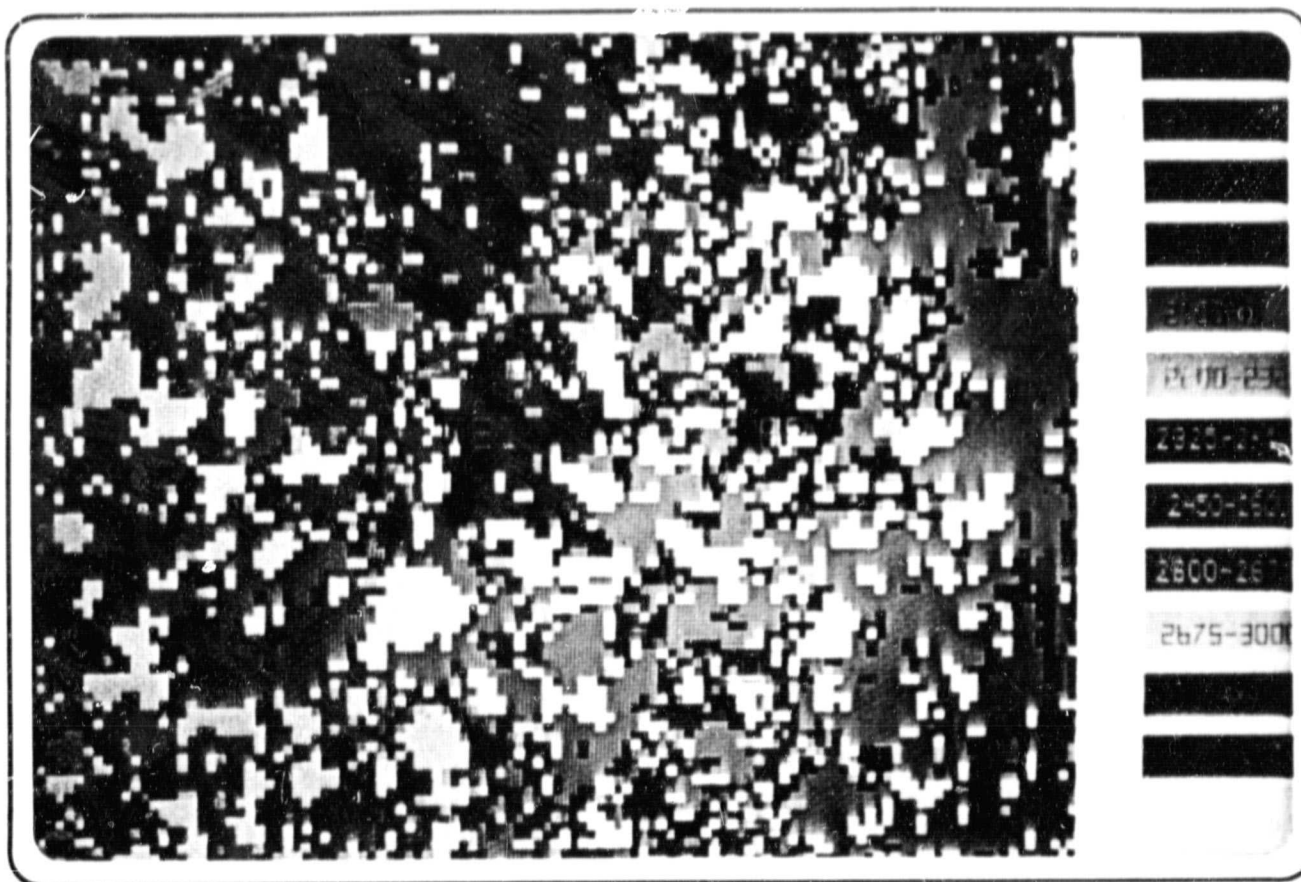


Figure 5. Smoothed Classification Preserving Linear Features in the X
and Y Directions Only.

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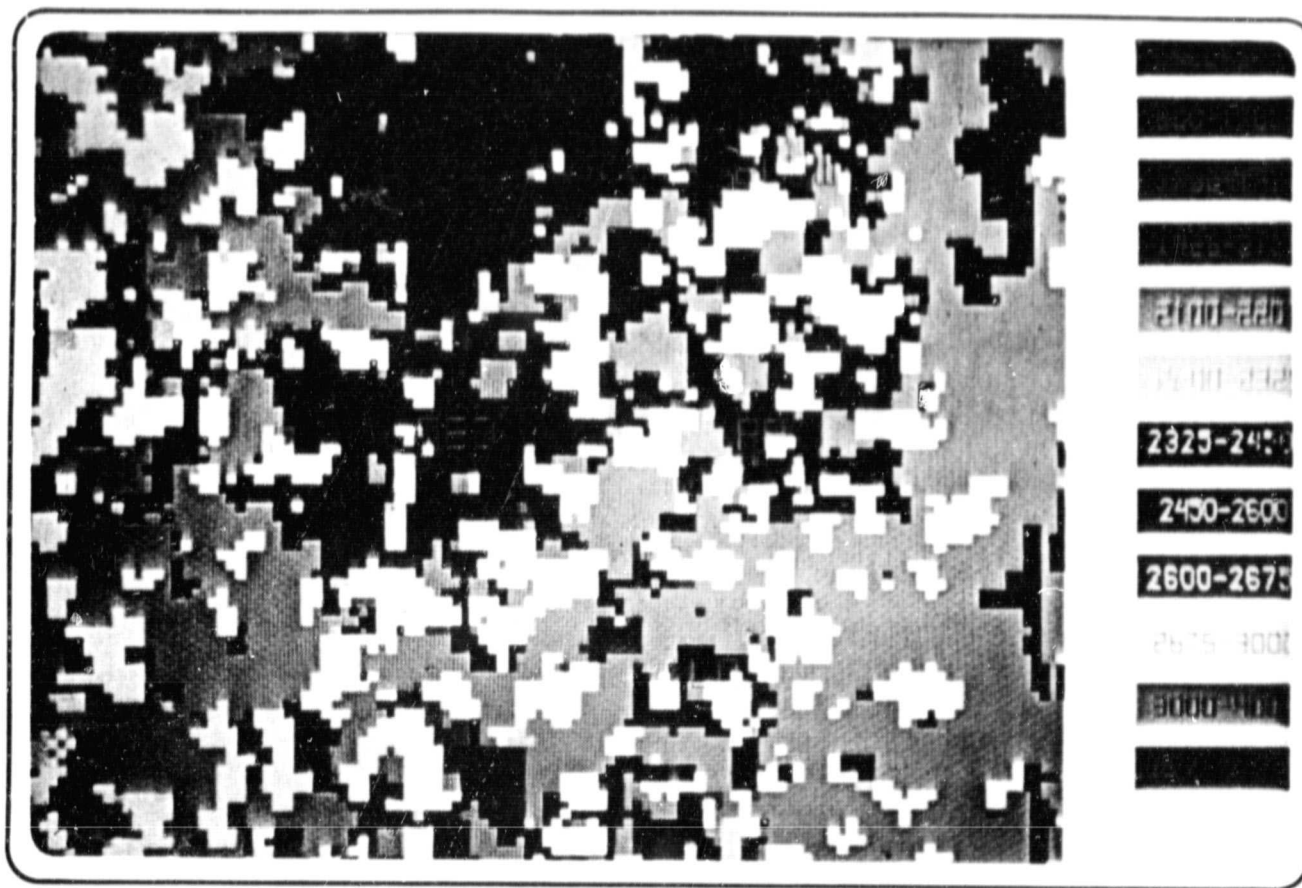


Figure 6. Highly Generalized Classification.

CONCLUSIONS AND RECOMMENDATIONS

The principal conclusion from this study must be that there is a definite relationship between film exposure and yield in SO_2 and acid rain-damaged soybeans. However, multiple linear regressions provide only a first approximation when a field situation is presented. Different stress agents seem to affect the relationship between exposure and yield in analogous but slightly different ways. Thus, quantitative description of the relationship requires extremely careful experimental design and meticulous attention to possible interactions between variables. While this study did not completely define the relationship between exposure and yield, we feel that it is an important first step in defining this relationship.

It must also be concluded that as flight height increases, color infrared film becomes the most useful sensor. This is most probably due to atmospheric interactions occurring in the blue region of the spectrum (.4 - .5 μm). Black and white (Tri-X) film is of the least use at higher flight altitudes but is reasonably usable at lower ones.

As one might expect, merging of plot data improves the results, as does eliminating as many shadow and soil data points as is possible.

Exposures from the red (chlorophyll absorption) band are most highly correlated with yield, with the green band producing redundant data. The infrared and blue bands were found to be relatively small contributors at high altitudes, but increased R^2 in the low altitude data.

From the above conclusions we recommend that if further study is to be made of this subject: 1) more plots be harvested such that the complete range of field conditions could be approximated, 2) each plot should be marked by a white panel, and survey data should be available for the location of each panel, 3) for efficiency, color infrared film should be flown at a

scale near 1:30,000, 4) multiband photography should be investigated, 5) the multirate aspect of this study should be investigated, beginning with a flight at the end of July and continuing through early September, and 6) it is suggested that the overall classification accuracy would be improved if a maximum likelihood classification was performed on the data prior to the yield classifier such that only soybean pixels would be classified using the yield classifier.

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